On-Site Runoff Mitigation with Rooftop Rainwater Collection and Use

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1 Introduction:

The construction of residential and commercial developments on the previously forested terrain of King County has had negative hydrological impacts on the streams of the region. A forested landscape typically infiltrates precipitation to the subsurface before it reaches a surface channel. After infiltrating, precipitation is both transported as baseflow and also recharges groundwater aquifers. Development creates impervious surfaces such as driveways, roads and rooftops thus causing a greatly increased volume of surface runoff. This increased surface flow causes increased peak flows during storm events and decreased magnitude of low summer flows. This altered flow regime both causes stream channel instability and damages aquatic life.

Historically King County has managed development impacts by requiring new development to construct plat scale retention/detention facilities. Though these facilities can be effective in reducing the magnitude of large events they require expensive real estate, continuing maintenance costs and do not replicate the natural flow regime.

Recently, after the listing of the Chinook and Bull Trout under the ESA, the County and other municipalities have had increased interest in new “low-impact” development techniques. The goal of “low-impact” development is to reduce large runoff volumes that traditionally have been created by development. Several on-site schemes for low-impact development are retention systems for use, forest retention, limiting impervious area, dispersion/infiltration systems, soil amendments, alternative landscapes, and permeable pavements. More recently, the County Water and Land Resource Division has been directed by the County Council to develop ways to reduce the impacts of the surface water management utility fee on rural developments. Identifying techniques for reducing runoff impacts from development, such as rainfall collection, could help ameliorate those impacts.

In this paper we address the feasibility of various rainwater use scenarios while forest retention, alternative landscapes, permeable pavements, and other schemes have been addressed by King County previously (Foley, 1999). Stormwater storage and use can reduce surface water runoff and reduce demand on potable water systems. This can reduce direct hydrologic impacts to streams from runoff as well as help to reduce demand on in-stream flows during critical summer low-flow periods.

1.1 Regional Precipitation Patterns

The Puget Sound region has an annual precipitation pattern that delivers wet winters and dry summers. Beginning around October and continuing through May the region experiences long-duration storms from three hours to two weeks periods (Gan and Burges, 1990). The annual volume of precipitation observed at SeaTac, the region’s rain gauge of longest record, averages near 35 inches. Though this is not a large annual precipitation volume, the wet winter, high frequency, long duration storms result in 55% of the annual rainfall eventually appearing as stream flow in forested catchments of King County (KCSWDM, 1998).

1.2 Background of Rainwater Harvesting

In remote areas where ground and surface water supplies are of inadequate quantity or quality, rooftop rainwater harvesting has provided an economical and reliable alternative water source. Rainwater collection is used today in Alaska (Johansen and Seifert), Australia (Forssell, A.B.C.), Africa (Gould, 1995), China (Zhu and Wu, 1995), many islands of the Pacific (Fontaine, 1987), Texas, Oregon (Oregonian), and even here in Washington. This technology which has been used for thousands of years has recently seen increasing usage in both modern and developing countries. The increase can be attributed to both governmental support and advances in the technology.

2 System scenarios for stormwater use and runoff mitigation

Stormwater storage and use can reduce surface water runoff and reduce demand on potable water systems. In this study small-scale detention/retention, infiltration, and indoor/outdoor use scenarios and combinations thereof are considered. Each of these scenarios has unique benefits and the optimal configuration may depend on site-specific conditions both of the users, the residence and the location.

The primary challenge faced in the design of a stormwater use system is balancing the differing rates of inflow and outflow (supply/demand). In the Pacific Northwest the supply of precipitation is high in the winter and low in the summer whereas the peak water demand is in the summer. This requires a large containment volume to store winter runoff for summer use. If a system is to be used as an outdoor water source and does not have adequate storage capacity to contain all of the annual inflowing precipitation, some measures should be taken to control overflow during the high discharge event dominated winter months. Overflow control measures should be designed to reduce the impact of the discharge by dispersing and infiltrating to the extent feasible. Specific control techniques are discussed in Appendix A.

An indoor and/or outdoor water use system would have benefits as a water source as well as reducing winter storm flows. Uses can include indoor potable, indoor non-potable and outdoor non-potable applications. Indoor and outdoor use systems require different system configurations due to water use patterns.

For example, a system can be designed with a large enough volume to contain all runoff and meet all needs, or a smaller system can be constructed which would infiltrate or release water to the surface when a designated capacity of the reservoir volume is reached. For a collected volume of water to provide adequate water supply for indoor or outdoor water use at a residence the containment volume must be large, on the scale of tens of thousands of gallons. In cases where containment volumes are not large enough to supply the needed demand, a secondary water supply such as a well or municipal connection would need to be used for some portion of the year. The process of determining the required system volume is discussed later in Sections 6 and 10.

A surface release mechanism would function similarly to a standard detention facility from the ecological perspective but when implemented on-site with a rainwater collection system could reduce the large plots of land required for large detention facilities. This could be economically beneficial to a developer and subsequent home purchasers. This method also has possible benefits in older developments where detention facilities have not been constructed and land is not available for facility construction. The relatively small size of rooftop collection systems can be incorporated into existing lots with little loss of usable space. This system scenario has the same collection and containment components as the other scenarios but some of the collected water is released to the surface instead of being used. However, this study focuses on water use scenarios and does not specifically address non-use configurations.

Infiltrating runoff on-site rather than discharging to the surface would better replicate the pre-development hydrology. By infiltrating on-site, basin hydrology will be closer to that of pre-development by increasing baseflows while also reducing surface flows. In this scenario the roof runoff is collected and a portion is released to an infiltration device. The infiltration device can be an infiltration trench, pond or drywell. The primary constraint on the performance of an infiltration system is the permeability of the soils at the site. If the infiltration rate were too small, an infeasibly large infiltration area would be required.

3 Parameter Estimation:

To assess the functional performance and cost of a system installed in King County, parameter values for an average home in a King County development were determined. Assumptions were made based on literature and past experience in regards to water usage, infiltration rates, and roof area. Later, in section 5, a discussion is made of how these water use parameters are incorporated into a simulation model.

3.1 Water Use

Indoor water usage values were established on a per capita basis. The 1999 study performed by the American Water Works Association Research Foundation (AWWARF) "Residential Water Uses" found a mean indoor water usage rate for the Seattle metropolitan region to be 59.8 gallons per day per capita. Following discussions with Seattle Public Utilities this value was determined to be the most representative for residential users in the region. Though this is an average value it is recognized that it includes some excessively high daily water uses. Small conservation steps such as fixing leaks and drips in homes can reduce this number significantly. Woods and Choudhury (1992) found national per capita consumption rates of 66.1 gallons per day without any conservation and 43.1 with moderate conservation.

A mass-balance model was implemented to simulate actual system dynamics on an hourly time step. In that model the hourly-variations in water use were incorporated in an effort to best replicate system dynamics. The daily distribution found in AWWARF (1999) is displayed in Figure 1.

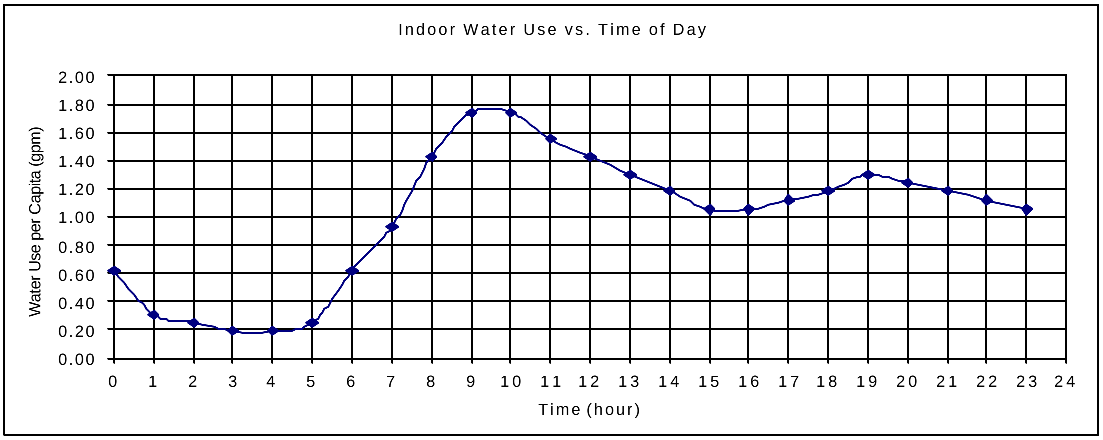

Figure 1: Daily Indoor Water Use Patterns

An arbitrary assumption in regards to a typical size for a household was made of 2.5. This is slightly smaller than a value of 2.8 found in the AWWARF study for a nationwide population. For comparison a household size of 1.5 was also considered. The total annual indoor water use per household assuming household sizes of 2.5 and 1.5 results in 52,560 and 32,745 gallons per year respectively.

Outdoor water use is based on the irrigible area of a residence. Shown below is a linear relationship from the AWWARF study which estimates annual water use based on a given application rate and irrigible area.

$$V = \frac{A(I)}{\left(0.13368\frac{ft^3}{gal}\right)\left(12\frac{inches}{foot}\right)} \qquad \textbf{(Equation 1)}$$

where A = inches of water applied to irrigable area
V = annual outdoor water use (gal)
I = irrigable area in ft^2

The AWWARF study found that for Seattle the average application rate (A) was 7.7 inches per year and the average irrigible area was 6058 square feet. Annual usage calculation using these values results in 29,000 gallons per year. In section 3.2 an approximation of rooftop area and impervious lot area is made from the King County Stormwater Design Manual (KCSWDM). We assume that the maximum irrigible area is equal to the difference between the total lot area and the lot impervious area, this results in 3600 square feet of irrigible area by our assumptions. This value is considerably less than that found in the population sampled by AWWARF but is a more reasonable number for a typical King County residence in a new urban subdivision. Applying Equation 1 with an 'I' value of 3600 results in 17300 gallons per year of outdoor water usage. Because these outdoor water usage statistics are bulk annual values, assumptions have to be made to determine the distribution throughout the year. We assumed that the total summer to total winter outdoor water use ratio is eleven to one, this relationship is plotted in Figure 2. Water use rates from the first of October until the last of April and from the first of May until the last of September and are calculated at 0.0107 and 0.1173 gallons per minute (gpm) respectively for AWWARF and 0.0064 and 0.0701 gpm respectively for the KCSWDM approximation.

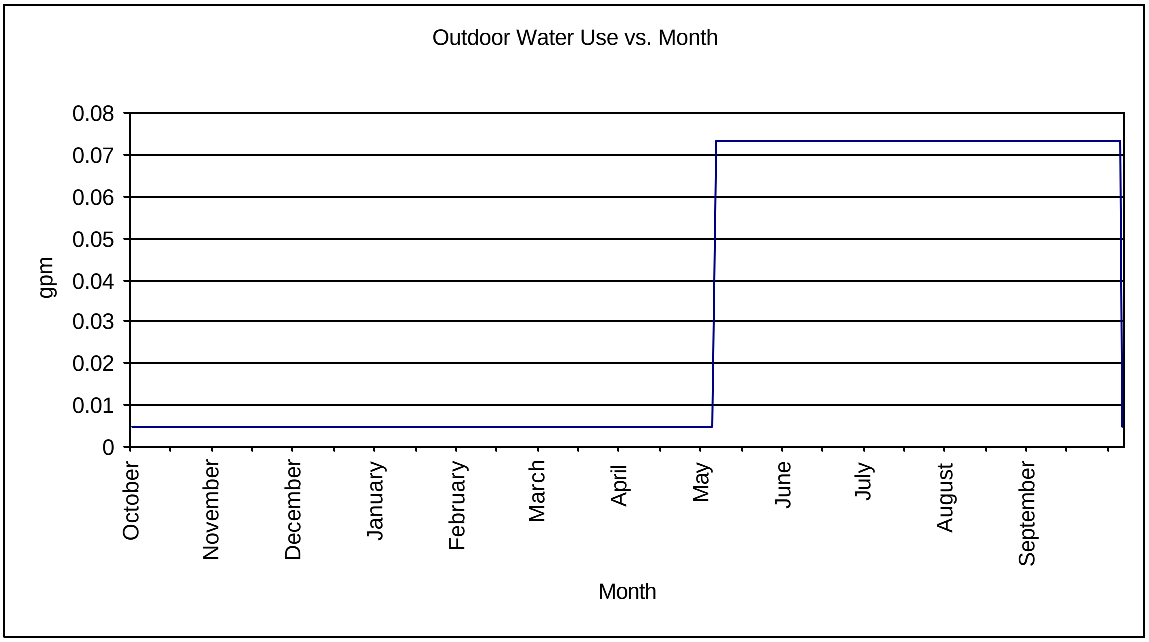

Figure 2: Annual Outdoor Water Use Patterns

It is recognized that outdoor water uses do not follow a step function as Figure 2. That is, users do not watch their calendar all winter and then at the end of May turn on the irrigation system and then turn it off promptly on the first of October. But this simple model is adequate for the mass balance simulations run in this study. An evapotranspiration relationship was considered based on the mean daily temperatures in the region but was not used because it did not seem to reflect realistic outdoor water usage patterns and simulated system performance varied only slightly.

3.2 Residential Rooftop Area

The supply of water to a rooftop collection system is directly proportional to the roof area of the rooftop at the residence. An average rooftop area was approximated from the standards adopted by the King County SWDM. The SWDM estimates impervious area using two different perspectives, as a percentage of the entire development and as square feet per lot.

An estimation of rooftop area from the percentage of the entire development method can be found using SWDM table 3-28. The table reveals that a typical R-4 lot density results in a development with 42% of its surface area impervious. From experience, we know that approximately half the impervious area is comprised of roads. Assuming that road right-of-ways, drainage tracts and sensitive areas take up 30% of a plat, lots make up 70% of the area. For an R-4 plat, this yields lots with an area of 70% of ¼ acre or about 7600 square feet. The lots are approximately 21% impervious or 2300 square feet. The house footprint then is 2300 minus driveways, sidewalks, patios, etc. resulting with an area near 1500 square feet. We know from looking at what is being built these days that this number is too small.

Under the square foot impervious per lot method in the SWDM we assume 4000 square feet of impervious per lot or the maximum allowed by code (KCC 21A.12.030), whichever is less. Subtracting a generous 1500 square feet for driveways, sidewalks, patios, etc. gives a house footprint of 2500 square feet.

These two methods of rooftop area estimation under the SWDM result in the average rooftop area being within the range of 1500 and 2500. For the simulations performed in section 5 the median value of 2000 square feet (185 square meters) is used as the average King County rooftop area. This value is close to the 2100 to 2500 square foot range that is assumed by Woods and Choudhury (1992) for the entire United States.

3.3 Infiltration Rates

Infiltration rates are very site specific and are critical to the performance of an infiltration system. The infiltration rates at a site are controlled by soil properties such as saturation, porosity, and permeability. An initial estimate for a commonly found till type soil is an infiltration rate of 1 foot per day (U.S.D.I., 1981). A second estimate for typical homes is the standard limit used for septic system permits by the King County Board of Health (KCBOH). Title 13 Table 13.28-4 of the KCBOH reports a maximum assumed infiltration rate for various soils. For a till type material a rate of 0.11 feet per day is recommended. A third and lowest boundary is from a field study on Vashon Till of the Sammamish Plateau by Konrad et al. (1995) that performed and infiltration test using a 1m single ring infiltrometer that found an infiltration rate of 0.1 mm/hr (0.008 feet per day). This wide range of values shows that soil infiltration rates in the region vary dramatically and rates must be determined for site specific conditions.

For simulations in Section 5 of systems using infiltration releases, parameters for a simple French drain were assumed. These assumptions were: a gravel depth of 2 feet, length of 50 feet, a width of 3 feet and a porosity for the gravel a conservative 0.3. Collection systems using infiltration trenches operate in the same manner as disposal type systems but have an added containment volume. The simulations run using infiltration systems have this added storage volume.

4 System Components

Regardless of the goal of a rainwater collection system, all have the same primary components: a catchment surface, storage facility, filtration mechanism and release mechanism. Depending on the goals of the design of a system, each of these components can vary dramatically. The designs may vary depending on the intended use of the system, required reliability, cost, available materials, local climate and other parameters.

The catchment surface is typically the rooftop area of the residence and gutters to transport it. Any impervious surface near a residence could be used with a rainwater collection system but contaminant hazards must be considered. A system configured for potable water use should not collect runoff from on-grade surfaces due to the higher risk of pollutants. Systems configured to infiltrate water to the sub surface must also consider the risk of polluting the subsurface by infiltrating surface pollutants.

A review of research on rooftop materials suitable for potable water system collection surfaces resulted in some useful information for rooftop material selection. Woods and Choudhury (1992) recommend ceramic tile and galvanized metal roofs to as efficient surfaces to quickly transport precipitation and minimize losses to evaporation. Their study also recommended avoiding the use of lead flashings or lead based paint. Galvanized surfaces were reported by Good (1993) to deliver elevated particulate zinc concentrations during the initial flushing of the roof during a storm and elevated dissolved zinc throughout the duration of a storm. Research covering many materials that would be expected to be safe (such as enameled metal, tile or cement tile) was not readily available.

The National Sanitation Foundation (NSF) certifies products for rainwater catchment systems. Products passing NSF protocol P151 (http://www.nsf.org/ers/pkgstate.html) are certified for use in drinking water systems. Products meeting the requirements of this protocol impart no contaminants at levels greater than those specified in the latest version of U.S. EPA's Drinking Water Regulations and Health Advisories. The only types of material not eligible for NSF certification are wood roofing materials.   Currently however the only products that have applied to NSF for certification are two coatings (Weather Barrier, Topcoat) and one flexible membrane liner (Flex Int'l). NSF representatives said they are eager to test and certify additional products, (such as metal, asphalt or tile materials) but have not been approached by any manufacturers. Possibly if a greater market for rooftop collection systems existed more manufacturers would seek this certification. If rooftop rainwater collection were recommended by a county or city agency it would be beneficial to recommend NSF certified products to users.

Storage facilities are typically the most expensive component of a collection system and can vary greatly in size, cost and material. Containers can range from 50-gallon drums to 50,000-gallon vaults. A system designed only to detain runoff from single large storm events could be small, but a system used for summer irrigation would need to be as large as possible to store the maximum amount of winter rainfall.

The size and type of a storage tank are dependent on the area available at the site and on aesthetic requirements. Above ground storage reservoirs such as that in Figure 3 are less visually acceptable but are also less costly. The total cost of subsurface reservoirs is nearly double that of above surface reservoirs (30-60 vs. 60-100 cents per gallon). Below 15,000 gallon storage volumes polyethylene or fiberglass storage tanks show the best value. Above 15,000 gallons concrete vaults are generally more cost-effective. In the large tank category concrete vaults are promising largely because they can be incorporated into the structure of the house foundation, thus reducing some associated costs. Figure 4 shows four possible reservoir configurations. See Appendix B for an additional discussion of reservoir costs and configurations.

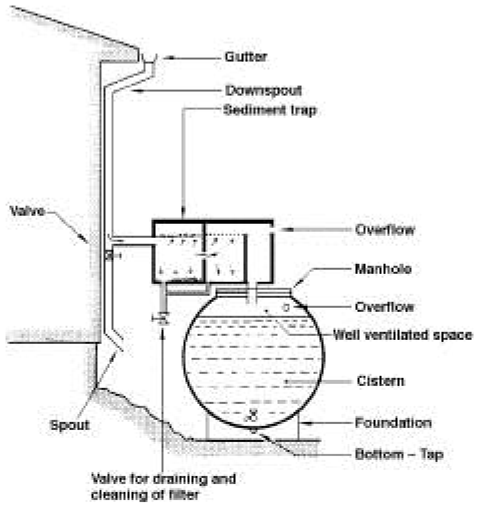

Figure 3: Typical Above Ground Reservoir Configuration (Stensrod, 1978)

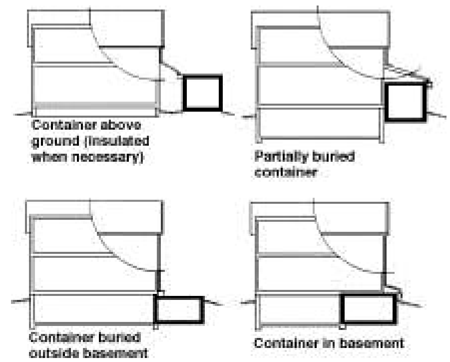

Figure 4: Various Possible Reservoir Configurations (Stensrod, 1978)

Filtration mechanisms vary depending on water use. All systems should have a debris filter to remove solids before water enters the storage tank. Users collecting water only for irrigation do not require post tank filtration or purification as indoor water users do For indoor water uses ultraviolet, reverse osmosis, carbon filter, chlorine and iodine have been recommended. Depending on the location of the catchment and surrounding land use, the quality of collected rainfall and therefore the necessary level of purification can vary dramatically.

The release mechanism is dependent on the potential head of the stored water. If a tank is located at an adequate elevation above the proposed use of water then no pumping is required. However if a tank is located below the base of a home then an inexpensive well-style pump will be required. These are typically submersible pumps capable of providing adequate water pressure to an entire home. Manufacturers recommend a pressure tank be installed for longer pump life and smoother operation. A pump and tank can be purchased for less than 200 dollars.

5 Performance Modeling:

To assess the performance of the various system configurations and to determine sensitivity of the various parameters assumed above a simple mass balance model was assembled (see Appendix C for model code).

The hydrologic record input to the model was eight "representative" years from the SeaTac rain gauge modeled over an impervious acre using KCRTS. This unit area discharge was then increased or decreased by multiplying the output by the acreage of the rooftop being modeled.

The performance of a configuration was then assessed by the output from the model simulations. The metrics used were 'percent of time having water shortage' and 'percent of time that surface release occurred'. 'Percent of time having water shortage' measured the performance of the configuration as a potable water supply source. If the tank was empty when the users needed water the percentage of time increases. 'Percent of time that surface release occurred' was an important metric because it provides a measure of the system's effectiveness in reducing surface runoff. It should be recognized that if implemented, a system would be designed with an orifice configuration that would prevent the rate of surface release from being as large as the rate simulated here or the surface flow from the system might be directed at a traditional detention facility. In Appendix D - Model Results - Figure 5 discharge from the system is plotted showing discharge spikes during surface releases of a high intensity storm. A system could easily be configured with orifices to release at elevated discharges for longer periods of time but with lower overall peak discharges. None the less, 'Percent of time that surface release occurred' still indicates whether a system water use rate completely eliminates surface runoff.

6 Modeling Results

Simulations were run for outdoor, indoor, and both indoor and outdoor water uses. For each water use several parameters were varied to characterize system performance under a variety of configurations. These parameters included system with tank volumes ranging from 1500 to 41,630 gallons, water use rates of 35.9 and 59.8 gallons per day per capita, rooftop areas of 0.047 and 0.099 acres (2047 and 4312 ft^2), and irrigible areas of 3600 ft^2 and 6058 ft^2. Appendix D - Table 5 displays values for simulations and their resulting performances.

Outdoor Only - Systems simulated with only outdoor water uses had adequate water volume for supply at tank volumes greater than 10,000 gallons when simulated with 3600 ft^2 irrigible areas and at volumes greater than 21,000 gallons when simulated with 6058 ft^2 irrigible area. For all outdoor use only configurations, the simulations resulted in surface flows occurring more than 22 percent of total time precipitation occurred.

Indoor Only - Indoor only simulations with a 0.047 acre roof area and lower water use rate of 35.9 provided adequate water volume supply in systems larger than 10,000 gallons but not at the higher 59.8 gallons per day per capita. Simulations with a 0.099-acre roof area provided adequate water supply at 59.8 gallons per day per capita with more than 21,000 gallons and performed well at other large storage volumes.

Both Indoor and Outdoor - Indoor and outdoor water use simulations with a 0.047 acre roof area and 3600 ft^2 irrigible area performed better for both water use rates at reducing surface releases than outdoor or indoor only configurations but adequate supply was not provided with any system volume. Increasing the rooftop area to 0.099 acres reduces 'surface release' performance but provides adequate supply with more than 21,000 gallon storage volumes.

Relationships between volume and system performance metrics are presented in four plots in Appendix D. Two of the figures (Figure 8 and Figure 9) display performance of a system with a 0.047 acre roof and two others (Figure 10 and Figure 11) display performance of a system with a 0.099 acre roof area.

7 Case Observations

Recognizing that there is a high value to observing case studies, an effort was made to locate some of the known existing water collection systems functioning in the Puget Sound area. One system in the City of Seattle and four on Marrowstone Island of Jefferson County are discussed in Appendix A. Because of saltwater intrusion and low aquifer recharge rates, many Marrowstone Island residents have looked to using rainwater collection as a supplement or alternative to groundwater sources. Two of the Marrowstone Island systems discussed are 38,000 gallons or more and two are 20,000-gallon systems. The system in the City of Seattle is small at 1500 gallons but is useful in observing a system functioning under the precipitation patterns of King County.

These functioning systems demonstrate several successful designs and some of the economic costs associated with them. It is clear by observing these cases that collection of rainwater has the potential to reliably supply a home in King County with indoor and outdoor water. The homes on Marrowstone Island have two or fewer residents and their indoor water use rates would be considered relatively low at around 35 or 40 gallons per day per capita, but the reliability of the large systems is encouraging. Large systems in King County should be more reliable (at least under the same water use rates) than those on Marrowstone Island because of the higher rainfall volumes observed in King County. Marrowstone Island lies in a rain shadow of the Olympic Mountains and receives an annual rainfall volume of 20 inches per year while King County typically sees 35 inches of rain annually. Though the volume of rainfall in King County is substantially higher than that of Marrowstone Island most of King County’s rainfall volume is observed during a third of the year, requiring a large containment volume to make this volume available as a year round water supply.

8 Legal Position of Authoritative Agencies

There are several agencies at the county, state and federal level that have interests in rainwater collection and use. The Washington State Department of Ecology (WSDOE) has authority over all rainwater collection systems, regardless of the end use. If collected rainwater is to be used as a potable water source the King County Department of Health, Washington State Department of Health (WSDOH), and United State Environmental Protection Agency (USEPA) have authority. Systems within unincorporated King County are subject to standards of the King Department of Development and Environmental Services (KCDDES).

A representative of the WSDOH was contacted who discussed the view of the State Health Department on the use of rainwater collection as a water source. The representative stated that the Health Department does not recommend rooftop rainwater collection as a potable supply. However, there are currently no laws specifically restricting the uses of the technology other than specific pollutant levels that cannot be exceeded. Of particular concern to rooftop collection systems are fecal coliform (from dead animals and bird droppings), and lead (from roofing materials).

A representative of the USEPA was contacted and discussed the legal requirements set by the USEPA. The USEPA classifies rooftop rainwater systems as surface water systems that would have to meet the federal criteria for filtration or avoidance of filtration (40 CFR Section 141.70: Subpart H). This code states that the water could be consumed but would need to be filtered to federal standards. If the water system supplies 15 connections or more than 25 people per day the system must meet requirements of the Safe Drinking Water Act (SDWA). Systems falling under the SDWA would require certified system operators and regular monitoring or inspections.

The NSF is a non-regulatory agency that only certifies materials for use in food and drinking water systems. The NSF certifies containment tanks for potable water and also has issued a protocol for roofing materials used in rooftop rainwater collection (NSF protocol P151 (P151 also includes protocol P3). The NSF protocol for roofing materials has only been authorized for use in tropical areas where rooftop collection is the only source of potable water and stated that these protocols would need to be re-tested in Puget Sound climate before they could be certified for use here. The protocol certifies materials for painting/coating roofing materials but does not recommend any particular roofing material over another (with the exception of not accepting any wood roofing material for use with potable collection systems). More discussion of protocol P151 is included in Section 4, System Components.

Systems in unincorporated King County must adhere to environmental and building standards of KCDDES. King County also manages building specifications. In large concrete reservoirs the structure must follow the King County building code (based on the Uniform Building Code).

The largest legal obstacle to this technology is due to the water rights control of the WSDOE. The WSDOE, by the Revised Code of Washington (RCW) 43.27A.020, controls “all waters above, upon, or beneath the surface of the earth, located within the state and over which the state has sole or concurrent jurisdiction.” and requires a legal water right for any use of that water. This means that any user of a rainwater collection system must first acquire a water right to collect. This is nearly an impossible task at the moment due to the Washington State water right system being backlogged until problems of over allocation and to few personnel can be overcome by the WSDOE. It was initially thought that a 5000 gpd maximum withdrawal rate that is set for groundwater withdrawal water-right exemptions would apply to rainwater collection systems. However it was determined that this exemption applies only to groundwater systems. A contact at the WSDOE has suggested that a possible modification to the code might be a “quick” water-right application for rooftop rainwater collection users. This would still give the WSDOE the authority to block large systems that would affect other water right holders. However, because the authority of WSDOE is granted under the RCW any changes to these requirements would require legislative action. But even without the law needing to being changed, it appears that WSDOE is not enforcing their authority in most situations (i.e. King Street Center, Marrowstone Island homes and the proposed City of Seattle Courthouse). Two exceptions are Camp Nor’wester on the San Juan Islands and possibly a golf course on Marrowstone Island. Camp Nor’wester is a retreat for youths that was required to establish a temporary water right. The temporary permit is appended in Appendix F.1. On Marrowstone Island it was reported that a golf course that was collecting huge volumes of runoff was forced by the WSDOE to stop collecting runoff or it would be faced with legal action.

9 Required System Maintenance

An issue of concern that will affect the use of these systems is the dependence on the homeowner for maintenance of the system. Any system configuration will require some sort of maintenance. The risk lies in the likely case of a neglectful homeowner who allows the system to clog with debris and overflow. The impacts of the high surface flows experienced during system overflow may be visible primarily off-site. To prevent a homeowner from not taking action during system failure, the design of the system must be such that the owner has an incentive to take the required action. This could be an overflow location that is readily visible, or possibly a warning light or audible alarm that can be observed from inside the home. The warning mechanism would be activated by an inexpensive flow meter in an overflow pipe.

Though rainwater collection systems require more attention from a homeowner than a traditional water supply, the time requirements are minimal. In systems used for non-potable water sources or infiltration, the collection system only needs a periodic clearing of a screen filter. This maintenance should be no more than an hour every year except in the most severe cases, depending on over-roof vegetation. Users of rainwater collection systems, who have subsurface storage tanks, report going years without having to enter the tank for cleaning. However an inspection should be made annually or biannually to check for cracks or algae growth within the storage tank.

10 Conclusions

In many regions outside the Pacific Northwest, precipitation falls uniformly throughout the year in a pattern allowing for a continuous capturing and usage of rain. However, in the Northwest a majority of the annual precipitation falls between the months of October and June while the highest water demand season is between May and October. This requires that for rainwater to supply a residence during the June to October time period all of the precipitation must be collected during the October to June time period. Even in moderately conservative homes this large volume of water will require a water storage reservoir of greater than 21,000 gallons for all outdoor or indoor usage. An indoor system of this magnitude may cost $24,050 (based on 400 dollar UV purification system, 15,000 dollar subsurface vault, 200 dollars plumbing, 300 dollar pump and pressure tank, and 50 dollar sand column debris filter). This cost is out of reach for most homeowners who are already within close proximity to municipal or public systems. For other rural locations where groundwater may not be easily available or its quality is inappropriate for potable supply, the cost may be more reasonable.

However, there are still large benefits to a rooftop rainwater collection system that is used as a supplement to a municipal or groundwater supply. A system such as the 1500-gallon tank used in case 5 (Appendix E) provides adequate supply for a small garden. At a total cost on the order of 500 dollars, this is affordable to many homeowners. With larger systems that significantly reduce municipal water use, savings can approach 150 dollars per year on the annual water bill (in areas with higher water rates the monetary savings could be significantly more). Besides the monetary benefits to the homeowner, benefits accrue to the ground and surface water systems of the region. By reducing peak runoff and reintroducing the collected rainwater back to the ground through irrigation (outdoor use) or through onsite wastewater system drainfields (assuming that the home is not on a sewage system) a more benign hydrology will exist. Reduced demand on the public water supply, which is likely drawn from surface waters in this region, preserves that much water for instream flow and improves regional hydrology.

11 Recommendations for Rooftop Rainwater Collection

Rooftop rainwater collection technology has promise for application in the Pacific Northwest. Large volume systems can provide adequate water supply for small households and reduce demand on regional water supplies. Though sizable costs are associated with large systems, when incorporated into building structures or developments at a large scale some costs may be avoided.

Other benefits from the technology could be reduced sizes of traditional detention facilities. Large and small systems alike when implemented in new developments could reduce the required capacity of traditional detention facilities. Developers could benefit more space for housing lots and possibly reduced demands on conveyance systems. At the present time, local regulations typically do not address rainwater use systems, but this is expected to change.

12 Recommendations for Future Research

Future modeling research could refine that which was performed in this study. Modeling efforts might incorporate more complicated release mechanisms (multi-stage orifice discharge for small outdoor water use systems, sensor activated systems, etc.). Also the use of a modeling platform more computationally efficient than Stella would allow for a time series longer than eight "representative" years to be simulated. Ideally the entire historical record would be simulated for the most accurate performance results.

Large scale modeling efforts should be performed to determine the reduced demand on traditional stormwater facilities in new developments. A model on the scale of a development (in which all the homes use rainwater collection) would be useful in determining the benefits in reduced size of the traditional storage facility and conveyance system components.

Further analysis should also be done to identify the technical and financial aspects of rainwater collection systems for commercial/non-residential uses – especially in rural areas and where large daytime populations may increase use for indoor non-potable consumption such as toilet flushing. Schools, for example, have large rooftops, large daytime populations and are in peak use during the entire wet season. These applications have potential to outperform residential systems because of increased surface area and potential for larger storage volumes.

This technology is ready to be tested on a large scale. Successful systems have been built on Marrowstone and other Puget Sound islands that have lower annual precipitation than King County. It has been proven to be safe, simple, reliable and effective. Though modeling exercises may give better predictions of system performance, the next step may now be for regional agencies to offer incentives to developers and homeowners who are willing to test the systems. After construction of prototype systems in the region the configuration of systems can be optimized for performance.

13 Acknowledgements

Throughout the duration of this paper I received input, direction and advice from various sources. For the vision and energy of this project I'd like to thank Bill Eckel and Steve Foley, both from King County WLRD. Bill first thought of this project and found the funding resources within the WLRD to fund the work. Steve first thought of many of the technical ideas and inspirations of this paper and continuously pointed my questions in the correct direction. I should also credit all the system owners, manufacturers, University of Washington colleagues, and other agencies for being so cooperative with my continuous phone calls and questions.

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Appendix A – Release Control Techniques

Release control techniques are recommended for small systems that would otherwise experience frequent overflow. When a system is allowed to fill to capacity and overflow (see **Figure 6**) the hydrologic impacts downstream during the event are not reduced by the facility. This can be prevented by either directing overflow to a traditional detention system downstream or designing systems to minimize overflow. Two possible on-site control techniques are a winter only-release orifice or an active high-precipitation detection release.

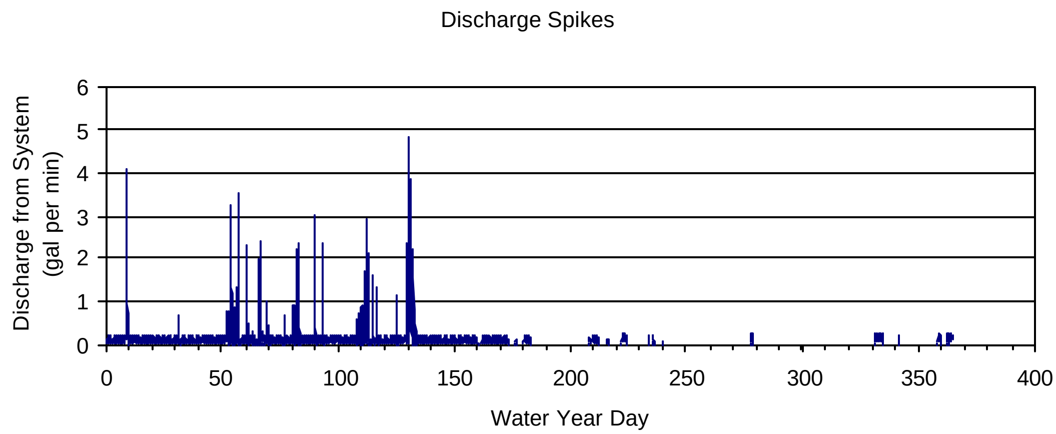

Figure 5: Discharge Spikes – These spikes show events that could not be captured by the system. The discharge from the system is both overflow and water used by users.

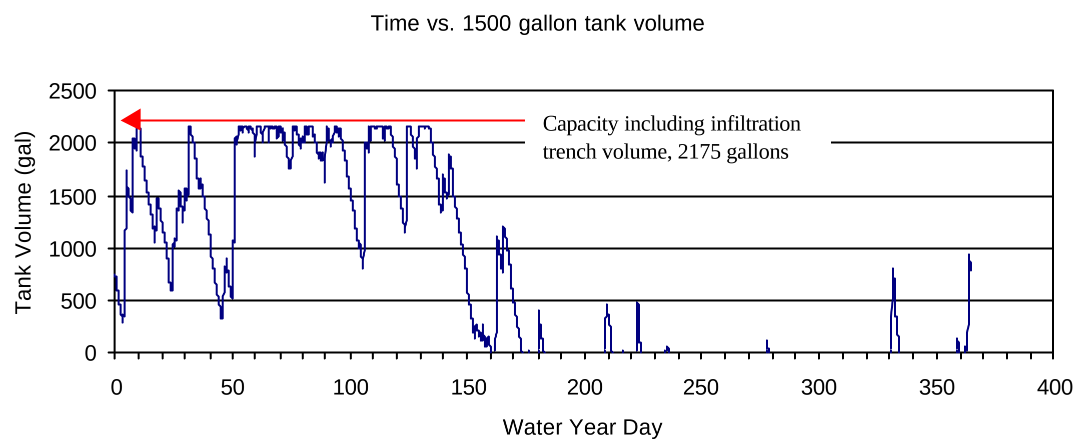

Figure 6: Time vs. stored volume for 1500 gallon tank system – Shows tank level as a function of water day year. Day zero is October 1st. This is the first year of the KCRTS 8-year "representative" record, which was a year with a 100-year storm event. (the water year begins on October 1st)

The winter only release orifice could be designed to release to the ground surface at an ecologically benign discharge rate during the winter months when inflow is much greater than outflow. Because indoor and outdoor water usage is sporadic and is not continuous, a continuous surface release mechanism would allow a better balance of inflow and outflows to the system. An orifice system similar to that in a traditional facility would release at a higher surface release rate when the reservoir becomes near full. (Shown in **Figure 5** is a system without an orifice release in its design. If an orifice were incorporated in the design the height of the discharge spikes would be smaller but they spikes would last for a longer period of time.) Conrad and Burges (1995) further discuss the effectiveness of various release rates in systems configured for surface release.

At the beginning of the winter months the surface release mechanism would need to be activated and again in the summer it would need to be deactivated. The activation could be either a hand valve or an electric solenoid valve operated by computer controller. Activation of a hand valve could be performed by the homeowner or possibly a county or city worker.

The active high-precipitation detection release technique would detect high volume precipitation events and would actively open a release valve for the duration of a storm or longer. One possible device for this are de-icing detectors used in the Eastern U.S. that detect precipitation. One rain activated release system (GOASE, DS-2B) shows promise at ($106, http://www.goase.com/ds2.htm). The manufacturer suggests that it could be easily programmed for this application. This study did not establish a release rule for this type of system.

Appendix B – System Components, Manufacturers and Prices

The most expensive component of a rainwater harvesting system is the containment volume or water reservoir used to store water for later release. The three types of water reservoirs considered here are above ground manufactured, below ground manufactured and below ground constructed. Prices from various manufacturers of reservoirs are presented below in Table 1. The quotes in the table give only the purchase price of the water reservoir and do not include costs of shipping and installation. Shipping costs vary dramatically depending on the number of tanks ordered and the distance shipped. When shipping tanks individually from Texas for example, shipping costs range from ten cents to thirty cents per gallon with smaller tanks being most expensive on a per gallon rate. Considerable discounts can be applied to shipping costs when full truckloads of tanks can be ordered.

The most expensive water reservoirs are those installed below the ground surface. These increased costs are due to the high costs of excavating material for below surface installation and increased structural requirements needed to carry added load of soil. The installation of subsurface tanks begins around twenty cents per gallon and increases depending on site-specific conditions.

Some of the costs associated with excavation can be avoided when water reservoirs are incorporated into a building structure. Frequently systems have been built of reinforced concrete and have been built at the same time as a home, barn, or garage foundation is poured. Because the construction of a foundation already requires excavation and concrete placement the added cost to incorporate a water reservoir is reduced. Marrowstone Homeowners incorporated large vaults (constructed water reservoirs) into residential foundations on the order of 20,000 to 40,000 gallons that varied between 10,000 and 20,000 dollars in cost. The least expensive of these systems was constructed by the homeowner who avoided labor costs. Incorporating labor costs would put the costs somewhere in the 15,000 to 20,000 dollar range for a 40,000 gallon water reservoir.

Table 1: Manufacturer Quotes for Above and Below Ground Water Reservoirs

Manufacturer	Volume (gallons)	Cost ($)	Cost ($/gallon)	Comments
American Process Technology	500	380	0.76	a,d
	1000	630	0.63	a,d
	2500	1100	0.44	a,d
	3000	1470	0.49	a,d
	5000	3100	0.62	a,d
American Tank	483	592	1.23	a,s,d, l
	1100	723	0.66	a,s,d, l
	2500	1193	0.48	a,s,d, l
	3000	1537	0.51	a,s,d, l
	5000	2924	0.58	a,s,d, l
	550	420	0.76	b,s,d,l
	1200	959	0.80	b,s,d,l
	1700	1100	0.65	b,s,d,l
B2 Equipment (Poly-Processing)	550	360	0.65	b,d,l
	1000	1160	1.16	b,d,l
	1200	890	0.74	b,d,l
	1700	1310	0.77	b,d,l
	500	567	1.13	a,d,l
	1000	1021	1.02	a,d,l
	2500	1962	0.78	a,d,l
	3000	2538	0.85	a,d,l
	5000	4060	0.81	a,d,l
	10000	6506	0.65	a,d,l
	16400	13276	0.81	a,d,l
Chemstor	525	470	0.90	b,d
	1200	665	0.55	b,d
	2500	1440	0.58	b,d
	5200	3150	0.61	b,d
Containment Solutions	550	1600	2.91	b,d
	1000	2250	2.25	b,d
	3000	3920	1.31	b,d
	5000	5100	1.02	b,d
	10000	7070	0.71	b,d
	15000	9990	0.67	b,d
	20000	14700	0.74	b,d
	30000	25835	0.86	b,d
	40000	37135	0.93	b,d
Texas Drinking Water Systems	100	135	1.35	a,d
	500	325	0.65	a,d
	1000	499	0.50	a,d
	2500	799	0.32	a,d
	3000	999	0.33	a,d

Comments:

a above ground
b below ground
s sale or discount price
d drinking water grade materials
l local (within 200 miles of Seattle, WA)

For applications where system reservoirs or catchment surfaces are located below the elevation of the point of use electric pumps and pressure tanks will be needed. Systems can be configured to have runoff pumped to a reservoir at a higher elevation immediately after passing through the downspout or the water can be stored at an elevation below the downspout and be pumped up on demand for use at a higher elevation. Storage of water at an elevation higher than the point of use can provide adequate pressure head for use without use of a pressure tank. In systems where water is stored below the point of use it is recommended that a pressure tank be used to provide smooth pumping and extended pump life. Table 2 includes prices from three manufacturers of pumps. When selecting a pump it is critical to purchase adequate pressure head to deliver water from the elevation of the storage reservoir to the point of use. In Table 3 quotes for pressure tanks are given for systems requiring their use.

Table 2: Pump Models, Performances and Costs

Manufacturer	Model	HP	Performance at head (gal per hour)				Max Head (no flow)	Cost
			5'	10'	15'	20'		
Flotec Inc.	S1250X	1/6	1050	840	480	0	18 ft	$59
	S1300A	1/4	1250	930	660	0	18 ft	$78
	S2400A	1/3	2760	2160	1410	0	20 ft	$98
	S3200A	1/2	3200	2700	2000	1200	24 ft	$130
Ridgid	AquaPro	1/3	3100					
	AquaPro	1	6000					
	Utility	1/4	1100					
	Utility	5 1/2	16800					
Little Giant	5-MSP		1200					$148
	5-ASP		1200					$164

Table 3: Pressure Tank Costs

Manufacturer	Capacity (gal)	Cost
Flotec Inc.	35	$159
	50	$218
	85	$274

This study performed a brief assessment of purification and filtration technologies that were available on the market. Common technologies used by a number of manufacturers are reverse osmosis, ultraviolet (UV), ozone, carbon filter, and ceramic filter. Following are brief descriptions of the methods used by these technologies to purify water.

Reverse osmosis uses a membrane that is semi-permeable to allow water to pass through it, while rejecting contaminants with larger diameters than the membrane gaps. Most reverse osmosis technology uses a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. **UV** purification uses short wave UV light that destroys bacteria, viruses and other microorganisms by interfering with DNA and RNA in the organism's reproduction cycle. **Ozone** technology oxidizes organic metals and most microorganisms allowing them to flocculate and be removed from water solutions. **Activated Carbon** technology removes chorine and heavy metals such as lead and iron as they are bound to carbon molecules as water passes through a filter. Many carbon filters also incorporate a **ceramic filter** that provides efficient sub-micron water filtration, which is advertised to remove hard-shelled parasites such as Cryptosporidium and Giardia lamblia.

A brief survey of filtration and water purification manufacturers was made to assess the costs of common technologies. In section 3.1 we discussed indoor water use and found that a typical resident uses less than 60 gallons per day, indoors. So when sizing water systems water use can be estimated by using this factor. We assumed that a typical home has 2.5 inhabitants and uses 150 gallons per day. This estimate however assumes that clothes washing, drinking, showering, cooking and toilet use is purified to the same standard. In many homes people may choose to purify kitchen water to a higher standard than other indoor water uses. See Table 3 for some various products that are available.

Table 4: Filtration and Purification Systems, Capacities and Costs

Manufacturer	Model	Type	Capacity (gal/day)	Capacity (gal/min)	cost
Texas Drinking Water Systems (www.texwater.com)	Sure IV	reverse osmosis	100		595.00
	TDWS 200	reverse osmosis	200		1595.00
	Silver	carbon filter	drinking H20 only		100.00
American Tank (www.americantank.com)		ozone			1995.00
British Berkfeld (www.watertanks.com/berkfeld)	imperial	ceramic filter	120		395.00
	crown	ceramic filter	165		495.00
	7"	ceramic filter	12		259.00
	9"	ceramic filter	24		279.00
Jade Mountain www.jademountain.com)	WC3467	carbon filter		"whole house"	1995.00
	WC181	carbon filter		10	1395.00
	WC183	carbon filter		65	4895.00
	WC184	carbon filter		300	16950.00
	WC1350	ozone		tanks up to 20,000	1400.00
	WC7004	screen		?	192.00
	WC150	UV + carbon filter		2	395.00
	WC151	UV + carbon w/ sediment rem.		2	450.00
	WC153	UV		10	518.00
	WC154	UV w/ sediment removal		10	618.00
	WC156	UV + carbon w/ sediment rem.		10	727.00
Free Drinking Water (www.freedrinkingwater.com)	RO-45	Reverse Osmosis	45		345
	RO-90	Reverse Osmosis	90		385
	RO-75	Reverse Osmosis (low pressure)	75		485
	RO-260	Reverse Osmosis	260		895
	RO-400	Reverse Osmosis	400		1190
	RO-900	Reverse Osmosis	900		1690
	RO-6000	Reverse Osmosis	6000		3995

Some users in rural settings have used collected water as a potable source but have not implemented any purification technologies. Even with primitive systems it is agreed that unless purification systems are in place, drinking of the “first flush” of rainwater should be avoided (Konrad, 1995; Thomas and Green, 1993; Good, 1993; Woods and Choudhury, 1992). This first flush of water delivers pollutants that have accumulated from the atmosphere, birds, roofing material, trees, dust, etc. The length of dry time considered significant can vary dramatically depending local conditions (industries, tree pollen, road dust, etc.) (Tillman, 2000; and Thomas and Green, 1993). Some of the Marrowstone Island users, which use collected water as a potable source, divert the summer and first autumn rains away from the reservoir. In regions such as Puget Sound where atmospheric pollutants are in high concentration some modern purification should be implemented when using collected water as a potable source.

T here have been several mechanisms used to prevent the accumulation of debris in the system reservoir. The most expensive product is from Jade Mountain (http://www.jademountain.com/waterProducts/rain-filters.html) that separates debris as it flows from the downspout. This device comes in a potable water use grade at $325 and an outdoor use grade at $215. Some less expensive alternatives are a gutter debris splitter (see Figure 7), a bucket with a small hole on a chain (U.N.E.P, 1982) or simply a sand column filter (Tillman, 2000).

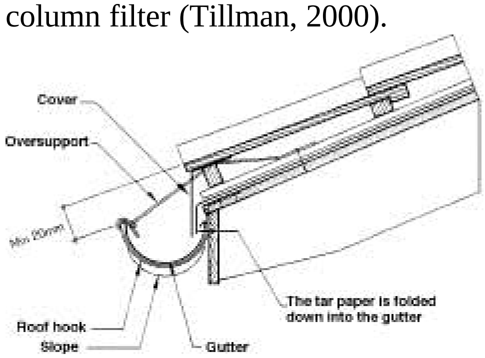

Figure 7: Gutter Debris Splitter (Stensrod, 1978)

Appendix C – Model Code

```
(see Stella Modeling Language file “rooftop.STM” for comments)
cost_of_water_per_ccf = 1.50/100
cost_of_water_per_gal = cost_of_water_per_ccf/cf_to_gallons
cost_per_year =
((indoor_avg_rate_gpm)*(60*24*365)+annual_outdoor_water_gpy)*cost_of_water_per_gal
Julian_Day = MOD(INT(TIME/(60*24)),365)
empty_time_total_min(t) = empty_time_total_min(t - dt) + (empty_time) * dt

INIT empty_time_total_min = 0
empty_time = IF (tank = 0) THEN 1 ELSE 0
min_of_uncontrolled_release_total(t) = min_of_uncontrolled_release_total(t - dt) +
(time_of_uncontrolled_release) * dt

INIT min_of_uncontrolled_release_total = 0
time_of_uncontrolled_release = IF((tank+(Inflow*DT))> total_volume) THEN 1 ELSE 0
overflow_volume(t) = overflow_volume(t - dt) + (overflow) * dt
```

```
INIT overflow_volume = 0
overflow = outflow-water_use_rate_gpm
raining_time(t) = raining_time(t - dt) + (raining) * dt

INIT raining_time = 0
raining = IF(Inflow>0) THEN 1 ELSE 0
ellapsed_time = TIME-STARTTIME
empty_% = empty_time_total_min/(ellapsed_time+1)*100
uc_%_of_raining_time = (min_of_uncontrolled_release_total/(raining_time+0.001))*100
uncontrolled_%_time = (min_of_uncontrolled_release_total/(ellapsed_time+1))*100
depth_of_water = (tank*gallons_to_cf)/(PI*(diameter/2)*(diameter/2))
diameter = 3
gallons_to_cf = (1/7.480519)
infiltration = 1
length = 10
tank_vol_add_from_infilt_trench = (trench_area*2*0.3)*cf_to_gallons
total_volume = IF(infiltration=1) THEN (volume_of_tank+tank_vol_add_from_infilt_trench) ELSE
volume_of_tank
trench_area = trench_length*trench_width
trench_length = 50
trench_width = 3
volume_cf = (diameter/2)*(diameter/2)*PI*length
volume_of_tank = volume_cf*cf_to_gallons
tank(t) = tank(t - dt) + (Inflow - outflow) * dt

INIT tank = 0.5*volume_of_tank
Inflow = roof_discharge_gpm
outflow = IF((tank+(Inflow*DT))> total_volume) THEN (tank+(Inflow*DT)-total_volume)/DT ELSE
water_use_rate_gpm
cf_to_gallons = 7.480519
per_sec_to_min = 60
roof_area = 0.047
roof_discharge_gpm = from_roof_cfs*per_sec_to_min*cf_to_gallons*roof_area
annual_outdoor_water_gpy = avg_irrigation_application_rate*irrigated_area_sq_ft/(0.134*12)
average_total_use = indoor_avg_rate_gpm+outdoor_water_use_gpm
avg_irrigation_application_rate = 7.7
day_to_min = 1/(60*24)
hour_of_day = MOD(INT(TIME/(60)),24)
indoor_avg_rate_gpm = members_in_household*indoor_use_rate_per_capita_per_day*day_to_min
indoor_use_rate_gpm = indoor_avg_rate_gpm*hourly_water_use
indoor_use_rate_per_capita_per_day = 59.8
irrigated_area_sq_ft = 3600
members_in_household = 2.5
outdoor_water_use_gpm = IF(Julian_Day>215) THEN annual_outdoor_water_gpy/(5.6363*24*60*30.42)
ELSE annual_outdoor_water_gpy/(62.000*24*60*30.42)
water_use_rate_gpm = indoor_use_rate_gpm+outdoor_water_use_gpm
hourly_water_use = GRAPH(hour_of_day)
(0.00, 0.62), (1.00, 0.31), (2.00, 0.25), (3.00, 0.19), (4.00, 0.19), (5.00, 0.25), (6.00, 0.62), (7.00, 0.93),
(8.00, 1.43), (9.00, 1.74), (10.0, 1.74), (11.0, 1.55), (12.0, 1.43), (13.0, 1.30), (14.0, 1.18), (15.0, 1.05),
(16.0, 1.05), (17.0, 1.12), (18.0, 1.18), (19.0, 1.30), (20.0, 1.24), (21.0, 1.18), (22.0, 1.12), (23.0, 1.05)
```

Appendix D – Model Results

Table 5: Water Use Simulation Results

Volume (gal)	Water Uses	Capita per household	Irrigible area (ft^2)	Roof Area (acres)	Percent Rain Time Uncontrolled Release	Percent Time Reservoir Empty
1500	outdoor	N/A	3600	0.047	75.19	24.16
5000	outdoor	N/A	3600	0.047	68.14	16.41
10000	outdoor	N/A	3600	0.047	57.35	6.11
21000	outdoor	N/A	3600	0.047	53.10	0.00
41630	outdoor	N/A	3600	0.047	45.75	0.00
1500	outdoor	N/A	6058	0.047	70.44	32.26
5000	outdoor	N/A	6058	0.047	62.59	26.61
10000	outdoor	N/A	6058	0.047	50.95	19.51
21000	outdoor	N/A	6058	0.047	33.59	5.01
41630	outdoor	N/A	6058	0.047	22.74	0.00
1500	indoor	59.8	N/A	0.099	50.04	34.11
5000	indoor	59.8	N/A	0.099	43.70	22.81
10000	indoor	59.8	N/A	0.099	39.10	15.46
21000	indoor	59.8	N/A	0.099	32.90	2.91
41630	indoor	59.8	N/A	0.099	30.10	0.00
1500	indoor	35.9	N/A	0.047	38.65	34.01
10000	indoor	35.9	N/A	0.047	23.20	10.31
21000	indoor	35.9	N/A	0.047	16.44	0.00
41630	indoor	35.9	N/A	0.047	8.24	0.00
1500	indoor	59.8	N/A	0.047	23.15	47.56
5000	indoor	59.8	N/A	0.047	14.24	40.10
10000	indoor	59.8	N/A	0.047	7.39	33.00
21000	indoor	59.8	N/A	0.047	2.64	26.01
41630	indoor	59.8	N/A	0.047	0.30	18.41
1500	in+out	59.8	3600	0.047	19.69	52.66
5000	in+out	59.8	3600	0.047	11.19	48.20
10000	in+out	59.8	3600	0.047	6.09	41.15
21000	in+out	59.8	3600	0.047	2.14	37.46
41630	in+out	59.8	3600	0.047	0.00	32.91
1500	in+out	59.8	3600	0.099	47.64	41.16
5000	in+out	59.8	3600	0.099	41.54	32.26
10000	in+out	59.8	3600	0.099	36.69	25.51
21000	in+out	59.8	3600	0.099	27.49	16.01
41630	in+out	59.8	3600	0.099	16.84	1.10
1500	in+out	35.9	3600	0.047	35.80	42.21
10000	in+out	35.9	3600	0.047	20.10	29.06
21000	in+out	35.9	3600	0.047	6.13	19.41
41630	in+out	35.9	3600	0.047	1.45	11.16
1500	in+out	35.9	3600	0.099	58.10	32.26
5000	in+out	35.9	3600	0.099	53.70	23.41
10000	in+out	35.9	3600	0.099	48.60	17.21
21000	in+out	35.9	3600	0.099	40.25	5.51
41630	in+out	35.9	3600	0.099	36.50	0.00

Outdoor simulations were run with no indoor water use.

Indoor simulations were run with no outdoor water use. Indoor use is simulated for 2.5 users in household at two consumption rates 59.8 and 35.9 gallons per capita. The water use rate 35.9 gallons per capita for 2.5 users is equivalent to 59.8 gallons per capita for 1.5 users.

In+out simulations were run with both indoor and outdoor water uses but only for 3600 ft^2 irrigible area.

Rooftop Area of 0.047 acres comes from KCSWDM assumptions; 0.099 was that of a Marrowstone Island resident

N/A data are not applicable to simulation.

Note: Simulations were run with an increased reservoir volume of 673 gal due to french drain volume.

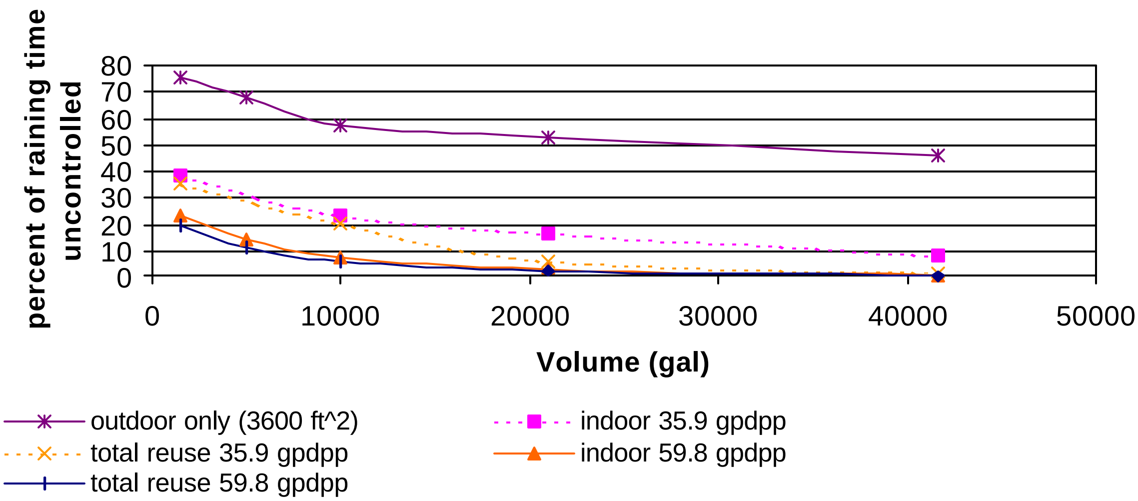

Figure 8: Reservoir Volume vs. Percent of Raining Time Uncontrolled Release (0.047 acre roof area)

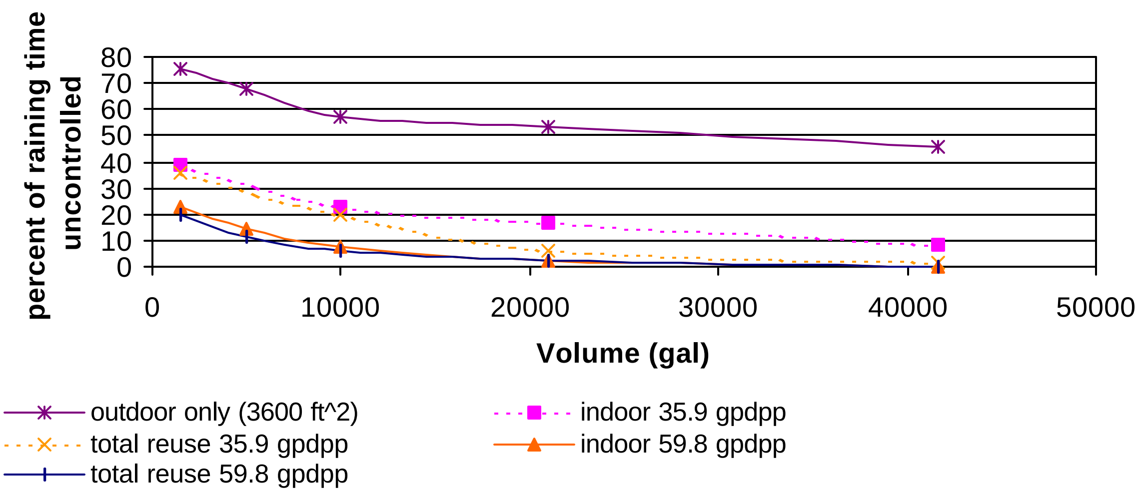

Figure 9: Reservoir Volume vs. Percent of Total Time Empty (0.047 acre roof area)

Note: gpdpp units are gallons per day per person

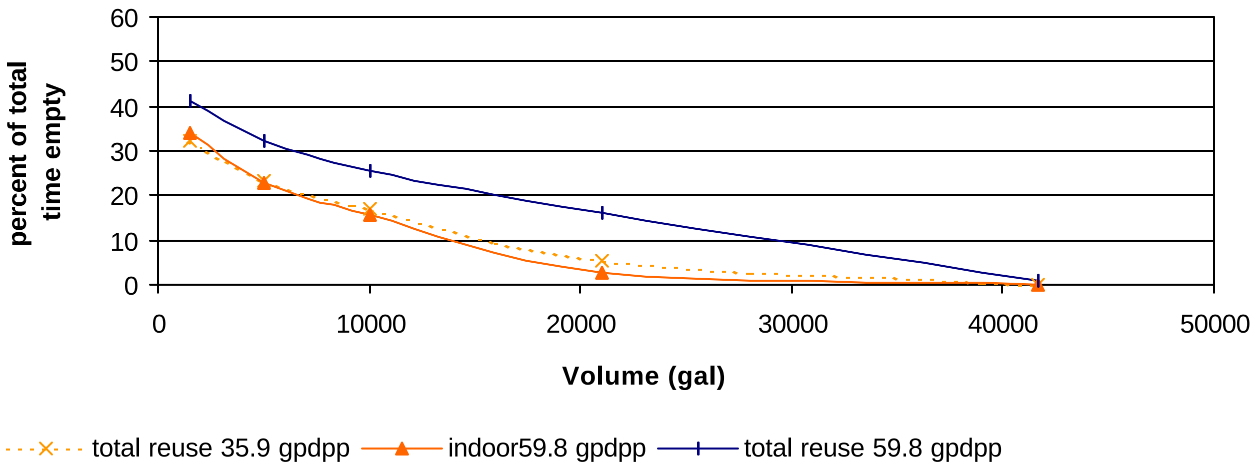

Figure 10: Reservoir Volume vs. Percent of Raining Time Uncontrolled Release (0.099 acre roof)

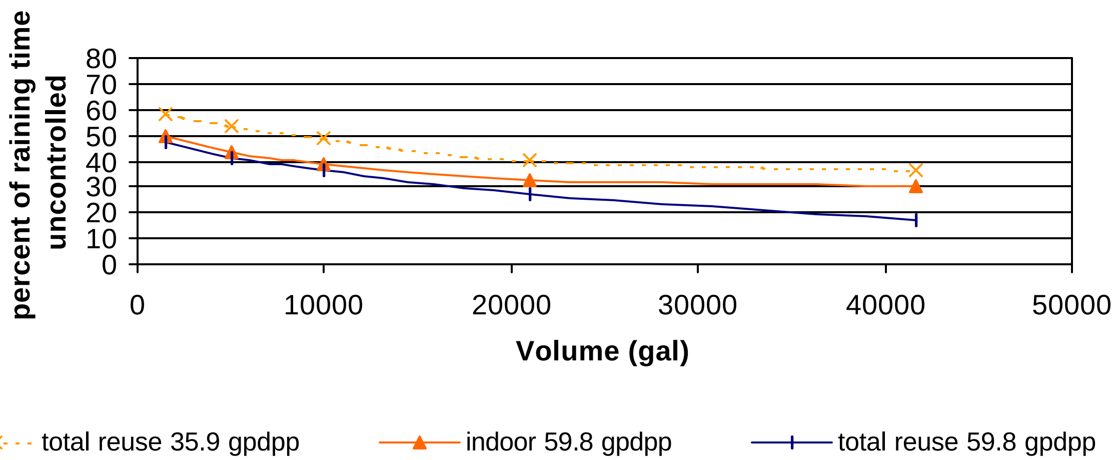

Figure 11: Reservoir Volume vs. Percent of total Empty Time (0.099 acre roof)

Note: gpdpp units are gallons per day per person

Appendix E – Case Observation Details

Phone interviews were made with half a dozen residents of Marrowstone Island and one Seattle resident to determine the cost and performance of rooftop collection systems currently in use. The residents were asked the following questions:

1) What is the size of the system storage volume?
2) How long was the system in use?
3) What types of uses do you use your system for?

4) How many people regularly reside in your home?
5) How often do you have water shortages?
6) What is the approximate area of your catchment surface?
7) What is the area that you typically irrigate?
8) What are the components in your system?
9) How often do you have to maintain your system?
10) Have you had any water quality problems?
11) What construction techniques were used?
12) What were the costs associated with the system installation?
13) Did you do the design and construction yourself or did you hire a contractor?
14) What are the annual maintenance costs for the system?
15) Is there anything that you would do differently if you did this again?
16) In what region of Washington State is your system located?

	System				
	1	2	3	4	5
1 – volume	42000+	38000 + 50(drinking)	20,000	20,000	1500
2 – years in use	8	10	7	12 (first 8 pond leaked)	3
3 – uses	drinking and irrigation	drinking and irrigation (drinking is on a separate system)	irrigation only	Irrigation only	Irrigation only
4 – residents in home	2	2	2	2	2
5 – shortage frequency	2 times total	1 time (faucet left on)	empty by every Labor Day	Annually	Annually
6 – catchment area	0.092 (acres) 4000 ft^2	0.099 (acres) 4300 ft^2	2 sides of gable roof doesn't know area	all of roof and curtain drains	0.0041 (acres) 180 ft^2
7 – irrigible area (acres)	0.5	1 acre (no lawn) just rhododendrons	5 acres including 2000 rhododendrons	(1/2" per week on 3200 ft^2) July 15 to Sept 1 (orchard/garden)	.069 acres (3000 ft^2) approx
8 – components	concrete reservoir, well pump, settling box, iodine injection, reverse osmosis	infiltration trench, concrete reservoir, peat gravel filter, well pump, charcoal drinking filter	Concrete reservoir, well pump, two sand filters	pond, 1/2 hp high pressure pump, well pump, 1/4" screen	tank, sand filter, piping
9 – maintenance frequency	clean screens 2-3 times during fall	cleans off peat gravel 2 or more times per year	once per year the sand filters are scraped clean	none	after large rain events sand is scraped clean
10 - quality problems?	none	none	none	Fecal coliform	none
11 - construction	concrete vault incorporated into guest home	concrete vault above ground (gravity feed after pumping up hill)	concrete vault below garage	Surface water pond	above surface (fiberglass or polyethylene) tank
12 - construction costs (construction year dollars)	10,000 for cistern	15,000 for cistern and 21,000 total cost	Unknown but Ryan Tillman reports 30,000 to 50,000 for these systems	\$1100 Excavation \$717 PVC liner \$734 topsoil	500 (cistern) + 200 parts

13 - contracted work?	self	self	Tillman Engineering	Self	self
14 - annual maintenance cost	zero	zero	none	none	none
15 - desired modifications		build below barn		use 40 mm thick plastic liner initially	indoor use and underground tank
16 - location	Marrowstone	Marrowstone	Marrowstone	Marrowstone	Seattle

System 1: This system has the largest volume of the residents interviewed. The owner has been using the system as a drinking and irrigation water source for eight years with never running out of water and never having water quality problems. The system uses two settling boxes in series to remove particulate matter; the boxes are cleaned twice annually. Additional purification is performed by an iodine injection system for potable cleaning water and a reverse osmosis system for drinking water. The owner will be changing the iodine injection system to a chlorinating system because the company that manufactured the iodine product is no longer selling supplies.

System 2: This system has been developed extensively. The owner has two separate catchment surfaces, one small area for drinking water and a large area for irrigation. The irrigation water is stored atop a hill in a 38,000-gallon tank. The unique feature of the system is that overflow from the tank is directed to a large infiltration trench in an attempt to recharge local groundwater. The system has been very successful with only one water shortage over the last ten years of use.

System 3: The system is used only for irrigation of 2000 rhododendrons located on the property and has a 20,000-gallon volume. The system runs out annually by Labor Day. One incentive for construction was a fire suppression reservoir. The remote location of Marrowstone Island has a delayed emergency response time and the reservoir could be used as a water supply until arrival of the local fire department.

System 4: The system is used only for irrigation and is stored in a 20,000-gallon surface pond (4.6 feet deep). The pond has tested positive for fecal coliform. In a typical summer season the pond is drawn down about 12,000 gal (15 inches).

System 5: The only contacted system located in King County is 1500 gallons and is used only for irrigation. The system fills in about 6 weeks beginning in the fall and goes empty every year. The tank loses huge volumes of water to overflow. He plans next to integrate the system into the plumbing of the house's toilets.

Appendix F – Literature and Documents from Other Washington Agencies

F.1 Department of Ecology (Camp Nor'wester permit)

f.4

STATE OF WASHINGTON

DEPARTMENT OF ECOLOGY

Northwest Regional Office, 3190 - 160th Ave S.E. • Bellevue, Washington 98008-5452 • (425) 649-7000

November 17, 1999

CERTIFIED MAIL
Z 410 722 196

Mr. Paul Henriksen
Camp Nor'wester San Juan Co.
62 B Doe Run Road
Lopez Island, WA 98261

Dear Mr. Henriksen:

Re: Preliminary/Temporary Permit Authorizing the Collection and Use of Rainwater under Application for Surface Water Rights No. S1-28018A

The above referenced application is a request to collect and use rainwater for multiple domestic purposes at Camp Nor'wester. Camp Nor'wester is seeking to collect rainwater (as needed) from approximately 18,000 square feet of rooftops at the rate of 80 gallons per minute and 0.767 acre-feet per year. Camp Nor'wester is located on the northwest half of Johns Island in San Juan County. The rainwater collection system and place of use will be located within the SE¼ of Section 26 and the NE¼ of Section 35, Township 37 North, Range 4 West. No protests were received during the statutory 30-day protest period.

Your request to establish a rooftop rainwater collection system for multiple domestic purposes (a Group A system) is a unique proposal. To date, this type of public water system has yet to go through the water right permitting process in the state of Washington. RCW 43.27A.020 articulates that the state has jurisdiction over all waters above, upon, or beneath the surface of the earth, located within the state. Based on this statute, rainwater must be considered as waters of the state. The Department of Ecology (Ecology) is the agency charged with administering the proper allocation of the waters of the state. RCW 90.03.290 allows for the issuance of a preliminary permit for testing and data collection purposes. RCW 90.03.250 allows for the issuance of a temporary permit for the appropriation of water. When appropriate, Ecology may issue a combined preliminary and temporary permit.

The location and geology of the San Juan Islands create an area of limited surface and ground water supply. Your proposal presents a unique opportunity to test the feasibility of rainwater collection as an alternative source of potable water supply. The results of your monitoring and testing program will provide the water availability information necessary for a final permit decision on your application and may possibly assist the state in the development of future water supplies. In addition, multiple domestic supply is considered a beneficial use of water and no detriment to the public interest could be identified during the

RECEIVED

review your application. For these reasons, you are hereby granted a Preliminary/Temporary Permit to proceed with the development, testing, and use of your rainwater collection system. Please check with the San Juan County Health Department and the Washington State Department of Health to determine whether additional approvals are required prior to construction and use of your system.

This letter shall serve as a Preliminary/Temporary Permit subject to existing rights and the following conditions:

1. This Preliminary/Temporary Permit will remain in effect for the pendency of your application, unless sooner revoked by the Department of Ecology.

2. If senior water right holders are adversely affected by the collection and use of rainwater on the Camp Nor'wester property, this Preliminary/Temporary Permit will be revoked.

3. The granting of this Preliminary/Temporary Permit shall not be construed, by inference or otherwise, that the subject application will ultimately be approved. If the applicant fails to comply with the terms of this Preliminary/Temporary Permit, it will be revoked.

4. For a minimum of two years after the first use of water, relevant information and data shall be collected and compiled into an annual report submitted to the Department of Ecology, Northwest Regional Office. This annual report must be submitted by January 31st for the previous year of water use. The Department of Ecology will provide written notice if additional data collection and annual reporting is necessary beyond the first two years of water use. Each annual report must include the following:

    a. Estimated quantity of rainwater collected and stored (in gallons per year).

    b. Metered quantity of rainwater consumed (in gallons per year).

    c. Metered quantities of water withdrawn from well 1 (and/or well 2, if brought into production). Include maximum instantaneous pumping rate and annual use (in gallons per year).

    d. Monthly static water levels from wells 1 & 2 and from the neighboring Sandeman well (coordinate this activity with the well owner). The Sandeman well should be measured at least once before pumping from well 1 or 2 commences. Static water levels shall always be measured at low tide. The tide level at the time of static water level measurement shall also be recorded. Any sudden or abnormal decline in static water level shall be reported immediately to the Department of Ecology.

e. Monthly chloride and conductivity readings from well 1 (and/or well 2, if brought into production). A laboratory certified by the Washington State Department of Health shall be used to perform the water sample analysis. Chloride and conductivity sampling shall always be accomplished at high tide. The tide level at the time of sampling shall also be recorded as part of the monitoring program.

f. Water quality readings from the Sandeman well (coordinate this activity with the well owner) in accordance with the September 1999, Pacific Groundwater Group monitoring plan. A laboratory certified by the Washington State Department of Health shall be used to perform the water quality analysis. Water quality sampling shall always be accomplished at high tide. The tide level at the time of sampling shall also be recorded as part of the monitoring program.

g. Precipitation data recorded daily from a rain gauge located as near as possible to your rainwater collection system.

5. All expenses, risks, and liabilities incurred during data collection and annual reporting shall be borne by the applicant.

This decision may be appealed. Your appeal must be filed with the Pollution Control Hearings Board, PO Box 40903, Olympia, WA 98504-0903 within thirty (30) days of receipt of this order. At the same time, your appeal must be sent to the Department of Ecology c/o Water Resources Appeal Coordinator, PO Box 47600, Olympia WA 98054-7600. Your appeal alone will not stay the effectiveness of this decision. Stay requests must be submitted in accordance with RCW 43.21B.320. These procedures are consistent with Chapter 43.21B RCW.

Should you have any questions regarding this Preliminary/Temporary Permit please contact Buck Smith at (425) 649-7147.

Sincerely,

Daniel Swenson
Section Supervisor
Water Resources Program

DS:ms

cc: Steve Deem, Washington State Department of Health

F.2 Jefferson County (location of Marrowstone Island)

JEFFERSON COUNTY HEALTH AND HUMAN SERVICES
ENVIRONMENTAL HEALTH DIVISION

POLICY STATEMENT NUMBER 97-01

PROGRAM: DRINKING WATER

SUBJECT: RAINWATER COLLECTION

I. Effective this date the following policy shall be adopted concerning the use of a rainwater collection system for proof of water adequacy for a building permit.

A. Rainwater collection systems (catchments) will be accepted as proof of meeting water adequacy requirements for a building permit as stated in Chapter 19.27.097 RCW, provided that the conditions outlined in this policy are met. All designs under review shall be submitted for individual catchment systems only. It shall be the applicant's responsibility to demonstrate that the catchment system provides adequate supplies of potable water; Jefferson County assumes no responsibility in the event of failure of the water system to provide potable or adequate supply.

B. Requests for review of catchment system designs shall be submitted as a catchment system design report. The catchment system design report shall be reviewed by Environmental Health staff. The report shall, at a minimum, address the following:

1) Estimated daily average and annual water demand based on an occupancy of two people per bedroom for residential structures. In the event that water usage is projected at less than 45 gallons per person per day, the report shall document how the use estimates have been derived.

2) Annual average precipitation in the location of the proposed structure.

3) Catchment area required based on 1) and 2) above with allowances for losses in the system and dry years.

4) Required storage volume based on a water balance analysis.

5) Storage tank conceptual design which provides for protection of the water from contamination while in storage.

6) A detailed description of a treatment system that provides for disinfection and filtration sufficient for the removal of suspended solids and cysts such as those of giardia and cryptosporidium.

C. In order to receive approval, the catchment system design report must demonstrate that an adequate supply of potable water will be provided. A copy of the report shall be retained with the building permit record. In addition, a notice shall be

To Derek Stuart		From Larry Fay	
Co./Dept.		Co. Jeff. County Hlth	
Phone #		Phone # 360 385 9436	
Fax # 206-296-0193		Fax # 360 385 9401	

Page 1 of 2

recorded with the property title. The notice shall identify the water source as a rainwater catchment system and specify the daily capacity of the system. The notice will not make any assurance of continued supply of potable water. A continued supply of potable water is assured only with appropriate operation and maintenance of the water treatment system by the owner, and with sufficient rainfall.

D. A combination system uses both a well and a catchment system to meet water demands. If used as proof of water adequacy for a building permit, a combination system may mix treated catchment water with well water provided that the catchment water is potable and meets all the requirements of Section B, above.

E. Combination systems may be constructed, and are encouraged for uses other than proof of an adequate water supply. If used, there shall be no cross-connection between untreated catchment water and potable water supplies, as per universal plumbing code standards.

II. As a part of the Growth Management Act, RCW Chapter 19.27.097 requires applicants for building permits for structures requiring a potable water supply to submit proof of an adequate supply of potable water for the intended purpose(s) of the building before a building permit may be issued. State Guidelines developed by the Washington Department of Ecology (DOE) and the Washington Department of Health (DOH) established the following criteria for adequacy of individual supplies:

* An adequate supply of water is 400 gallons per day for a single family residence.
* Potable water conforms with state drinking water standards (at a minimum, bacteriological quality and nitrates).
* Whole house treatment is allowed, and is recommended if water quality does not meet drinking water standards.
* Alternative sources of supply (including catchments) may be adequate if all other criteria are met.

Jefferson County Resolution 99-90 adopted the guidelines for the purposes of administering RCW 19.27.097. The Jefferson County Board of Health adopted Policy_93-02, "Water Availability Requirements for Building Permits," which is consistent with County Resolution 99-90. However, neither of these policies directly addressed the use of rainwater catchment systems to establish proof of an adequate supply of potable water. This catchment policy more specifically defines how Jefferson County will interpret the conditions required for alternative sources of supply in the state regulations.

Health Officer	5/21/97 **Date**
Chairperson Board of Health	5/16/97 **Date**

Page 2 of 2

F.3 San Juan Island County (location of Camp Nor'wester)

Health & Community Services
San Juan County
P.O. Box 607 – 145 Rhone,
Friday Harbor, WA 98250
Phone (360) 378-4474 Fax (360) 378-7036

RAINWATER CATCHMENT CHECKLIST

Applicant: ______________________ Telephone: ______________

Tax Parcel: ______________________

The design for a rainwater catchment system is required to contain the following information:

☐ 1. A scaled layout sketch of the system showing the system design.

☐ 2. A completed rainwater catchment water budget (see attachment A- include with Operation and Maintenance Manual).

☐ 3. Description of how the system works. Include system components and their uses and the number of persons the system is designed for (include with Operations and Maintenance Manual).

☐ 4. Materials Used. Items C-F must be comply with NSF, FDA, or AWWA Drinking Water Standards for potable water (include model #, manufacturer and NSF, FDA, or AWWA certification):

- ☐ A. Roofing Material (enameled metal, tile or cement tile):______________.
- ☐ B. Rain gutters (PVC or enameled metal): ______________________.
- ☐ C. Pre-storage filtration (prior to storage tank): ____________________.
- ☐ D. Water Storage Tanks: ______________________________.
- ☐ E. Filtration (must meet NSF Standard 53 or 58 for cyst removal – see Appendix A, page 4 *Filtration for Household Use* for specifics).
  ____.
- ☐ F. Disinfection (chlorination, ozone or ultraviolet [ozone and ultraviolet units must have a system failure warning device]): ____________________.

☐ 5. A completed *Declaration of Covenant for an Alternative (Non-Standard) Water Source* (must be recorded with County Auditor after approval of water system).

☐ 6. An approved Operation and Maintenance Manual (containing at a minimum of the items listed in attachment A). This can be included on page 2 of the *Declaration of Covenant for an Alternative (Non-Standard) Water Source* and must be recorded with County Auditor after approval of water system.

For further information on rainwater catchement, see pages 1 & 4 of Appendix A of the Rules and Regulations of the San Juan County Board of Health Regarding Water Wells and Water systems: Guidelines for Rainwater Catchment & Filtration for Household Use.

N:/environmental health/drinking water/form/rainwater catchment checklist.doc revised: 3/99

Attachment A

Rainfall Catchment Water Budget

Step 1	Number of users:		________	
	Gallons per day/person:	x	________	
	Gallons per day:	=	________	(users x gpd /p =)
Step 2	Gallons per day:		________	(see total for step 1)
	Days in residence/year:	x	________	
	Total water use per year:	=	________	(gpd x days of use =)
Step 3	Rainfall (see attachment B):		________	
	Water per sq. ft/inch of rain:	x	0.623	
	Gallons water/sq. ft./year:	=	________	(rainfall x .623 =)
Step 4	Total water use per year:		________	(see total for step 2)
	Gallons water/sq.ft./year:	÷	________	(see total for step 3)
	Sq. ft. collection area needed:	=	________	(divide total water use by Gallons water/sq, ft./year)
Step 5	Days of storage needed:		________	(90 or # of days in step 2)
	Gallons required per day:	x	________	(see total for step 1)
	Gallons of storage required:	=	________	(days of storage x gpd)

REQUIRED COLLECTION AREA (roof sq. footage): ________ (see total for step 4)

REQUIRED STORAGE CAPACITY: ________ (see total for step 5).

Operation and Maintenance Plan

Roofing: Roof should be cleaned as needed or at least once per year..

Rain Gutters: Gutters should be cleaned at least monthly during winter storm season to prevent accumulation of debris, leaves and needles. Screens should be installed on top of downspouts to prevent accumulation of debris from getting into system.

Pre-storage filtration: Designed to prevent accumulation of sediments and other particles in water storage tank(s).

Storage Tanks: Should be cleaned and disinfected as needed or at least once per year.

Filtration: Operation and maintenance of the filtration system is critical. If proper maintenance is not followed, contaminants can pass through the filter and/or collect and multiply on the filter's surface. Specific maintenance schedules are based on manufacturer's recommendation.

Disinfection: If manually chlorinated, describe procedure. All other types of disinfection (automatic chlorinator, ozone, ultraviolet) will have specific maintenance schedules based on manufacturer's recommendations.

Specifications and design for this system are on file with San Juan County Health & Community Services.

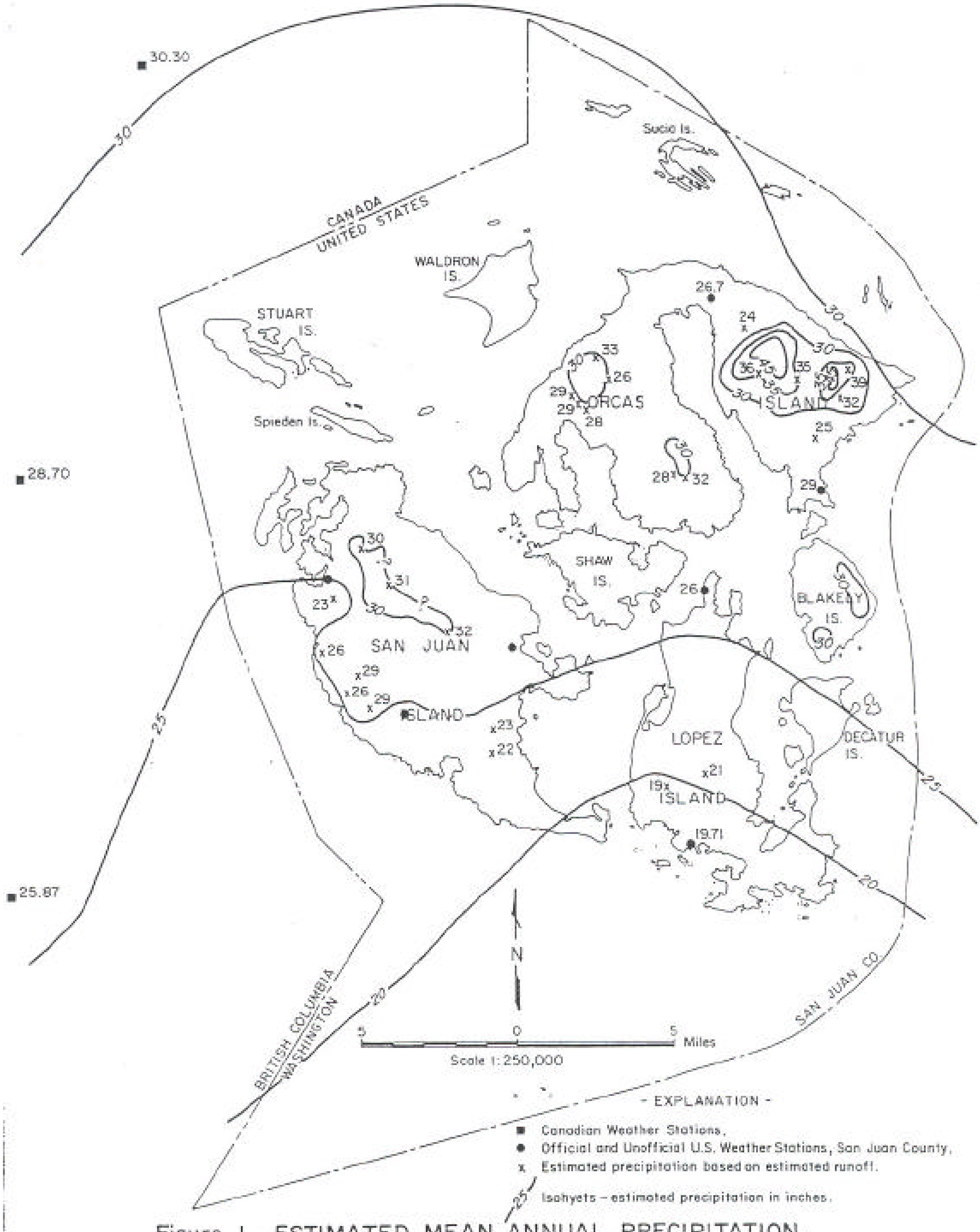

Figure 1. ESTIMATED MEAN ANNUAL PRECIPITATION.

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